

7.0 ONBOARD GROUND INERTING

The OBGIS is a self-contained method of providing inert gas to the airplane's fuel tanks without relying on an airport to supply the inert gas.

The Onboard Inerting Designs Task Team reviewed the 1998 ARAC FTHWG report for inerting and determined that most of the nitrogen inerting technologies discussed in that report remained unchanged. The team chose to focus on air separator technology because of improvements in technology and manufacturing and a probable benefit of reduced cost.

7.1 SYSTEM REQUIREMENTS

The Tasking Statement requires that the OBGIS inert fuel tanks be located near significant heat sources or fuel tanks that do not cool as quickly as unheated wing tanks. The affected fuel tanks will be inerted on the ground between flights. We will provide the benefits and risks of limiting inerting to fuel tanks near significant heat sources. This report will consider methods to minimize system cost, such as reliable designs with little or no redundancy, and recommendations for dispatching in the event of a system failure or malfunction that prevents inerting one or more of the affected fuel tanks.

We will describe secondary effects of the system, along with an analysis of extracted engine power, engine bleed air supply, maintenance effects, airplane operational performance detriments, dispatch reliability, and so on.

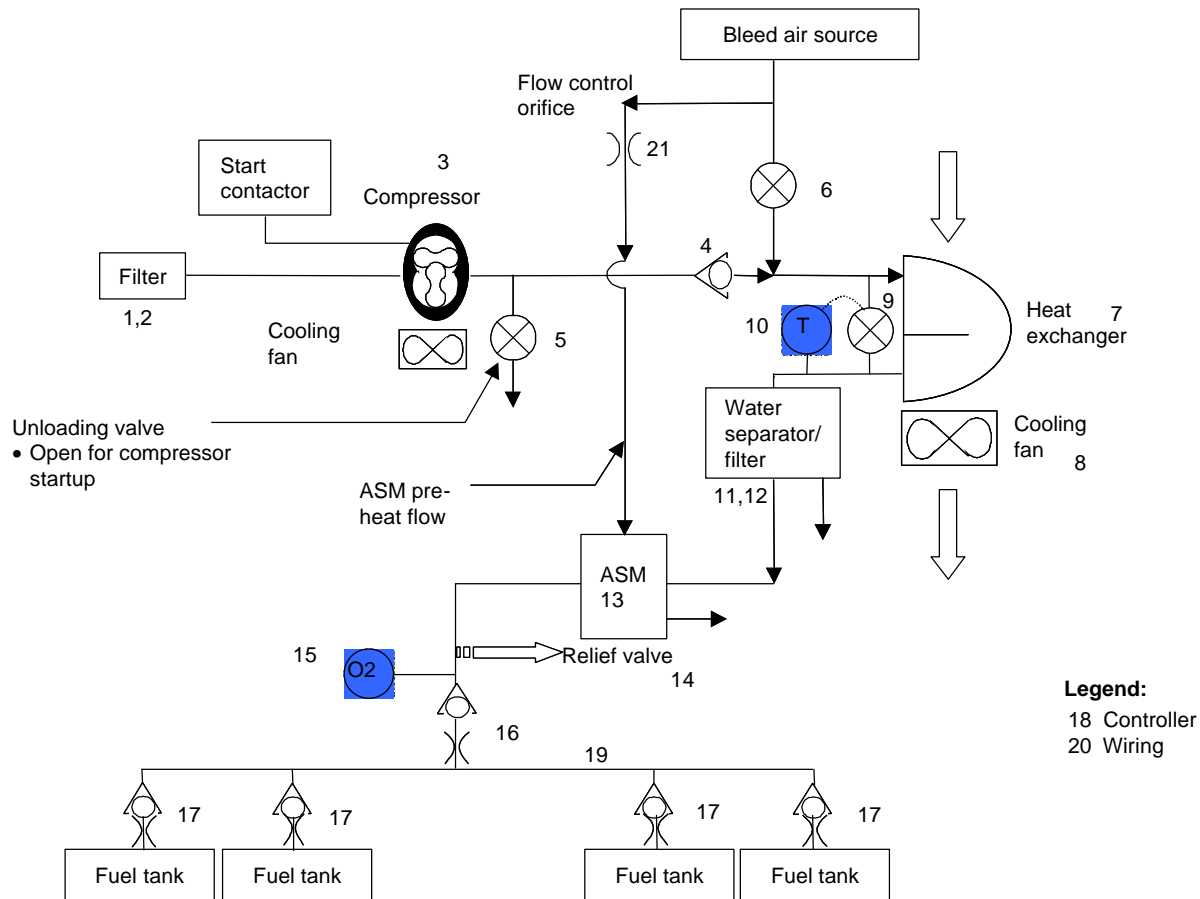
The Tasking Statement also required that information and guidance be provided for the analysis and testing that should be conducted to certify the system.

If the Working Group cannot recommend a system, the group is to identify all technical limitations and provide an estimate of the type of concept improvement that would be required to make it practical in the future.

7.2 CONCEPT DESCRIPTION

Figure 7-1 shows the OBGIS. In its simplest terms, an air separator module (ASM) separates pressurized air into nitrogen and other gases. The ASM supplies nitrogen to the fuel tanks and exhausts the other gases overboard.

The ASM gets pressurized air from either the engine as bleed air or from an electric compressor. This air is cooled if necessary, water is removed to avoid icing, and the dry air is then filtered to avoid ASM contamination.



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Figure 7-1. OBGIS Schematic

7.2.1 Air Source

The concept uses multiple air sources. Pressurized air can be provided by engine and APU bleed air or by the electric compressor. The air pressure supplied to the ASM is nominally 45 psia.

7.2.2 Pressure Ratio: Match APU Pressure

The electric compressor was sized for a 3:1 pressure ratio in an attempt to supplement bleed air with compressor air to minimize the compressor size and cost. However, check valves would need to be installed to prevent bleed air from creating backflow in the compressor or compressor air from backflowing into the engine. Neither pressure source could supplement the other because the source of higher pressure would close the check valve on the other source. A more complex flow-sharing concept was not pursued.

7.2.3 Air Separator

We studied three concepts for air separation. Hollow-fiber membranes separate nitrogen through molecule-sized passages when air passes through the length of the fiber. Pressure-swing adsorption (PSA) adsorbs oxygen as air passes over the module, leaving nitrogen in the flowstream. Cryogenic distillation relies on separation of a partially liquefied airstream using a distillation column. The product is a high-purity nitrogen gas, which can be sent to the fuel tanks, or a high-purity nitrogen liquid, which can be stored for later use.

7.2.4 Time for Inerting

Like the Ground-Based Inerting Designs Task Team, the Onboard Ground Inerting Designs Task Team assumed that airline operation should not be affected by the addition of the inerting system, if possible, to minimize the cost to the airlines. The primary operation where an impact should be avoided is “gate time,” that is, the time between flights when the airplane arrives at the gate, passengers deplane, the airplane is refueled, and new passengers board for the next flight. One of the design ground rules then was to inert the fuel tanks within the average minimum turnaround time at the gate.

Gate time depends on the airplane size and its use by the airline. Large airplanes have longer gate times because they have long flights and need more time to refuel and board passengers. Small airplanes have short gate times because they have shorter flights.

System size depends on the ullage volume and the gate time. A large ullage volume will require a lot of inert gas to fill it and, if the gate time is short, the inert gas will have to be generated quickly. This requires that the compressor, ASM, heat exchanger, and all interfacing components be large. The weight increases and the electrical power demand of the compressor increases.

“Initialization time,” or the time to inert a fuel tank after it has been opened and vented for maintenance, was estimated after the system size was determined. This was not considered an operational constraint because operators can plan their effort to allow time to inert the fuel tanks after maintenance.

This was a reasonable assumption at the beginning of this ARAC effort because fuel tank maintenance was normally performed only when a failure was noted. This may change and incur potential cost increases because of SFAR no. 88, the result of which may require more frequent tank entries. However, no effort has been made to determine the potential added cost impact of SFAR no. 88.

7.2.5 Flammability Exposure

The flammability exposure is defined as the percentage of the airplane mission when the fuel ullage is flammable and not inert. The 1998 ARAC FTHWG found that CWTs had a flammability exposure of approximately 30% and wing tanks had a flammability exposure of approximately 7%. The FAA has since been refining a model for flammability exposure, which was provided to this ARAC to compare system benefits. The OBGIS reduces the flammability exposure of a heated CWT to at or below the exposure of an unheated wing tank.

7.3 APPLICABILITY OF CONCEPT TO STUDY-CATEGORY AIRPLANES

The design concept applies to all the airplanes in the study category. However, the high electrical demand may exceed the capacity of the existing airplane electrical systems and, at airports that discourage APU operation, the airport’s ability to provide the electricity.

An inerting system can be designed into future airplanes, provided the inerting system size is calculated before engine, APU, and electrical generator selection. This will ensure that bleed air or electrical power is available to supply the inerting system.

7.4 AIRPORT RESOURCES REQUIRED

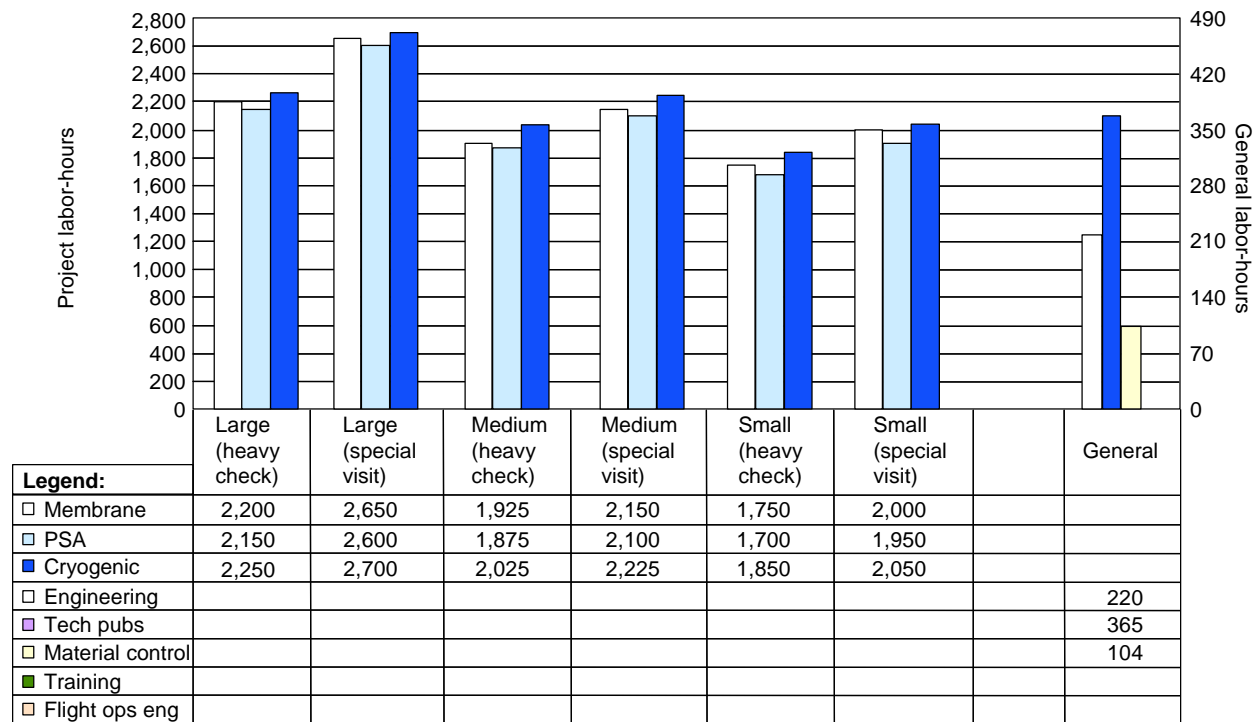
Electrical power from the airplane APU is needed to power the OBGIS. Some airports are sensitive to noise and do not permit APU operation, requiring a ground power source to supply the system.

7.5 AIRLINE OPERATIONS AND MAINTENANCE IMPACT

This section discusses the modification of in-service airplanes to install an OBGIS and the overall effect of OBGIS on airplane operations and maintenance requirements.

7.5.1 Modification

Figure 7-2 shows the modification estimates for the OBGIS. Because there is insufficient space for the OBGIS in the unpressurized areas of regional turbofan, regional turboprop, and business jet category airplanes, we have excluded these airplanes from this estimate. Estimates are made for both a regular heavy maintenance visit and a special visit.



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Figure 7-2. Modification Estimates for the OBGIS

The modification estimates for the OBGIS are based on the estimates of the OBIGGS; however, because the OBGIS is designed only for the CWT and auxiliary tanks, we have reduced the labor estimates to account for installation differences. The following reductions are used:

- For the large-airplane category: 300 labor-hours.
- For the medium-airplane category: 250 labor-hours.
- For the small-airplane category: 200 labor-hours.

The left side of figure 7-2 shows the estimated modification labor-hours per airplane for the different airplane categories. The right side shows the general support labor-hours. The support labor-hours are incurred on a per-operator basis as opposed to per-airplane and are approximately the same for all airplane categories. Task-level detail data used for the estimate is presented in addenda F.A.1 and F.A.2 of appendix F, Airline Operations Task Team Final Report.

7.5.2 Scheduled Maintenance

Scheduled Maintenance Tasks

A list of scheduled maintenance tasks was developed using the OBGIS schematic provided by the design team. The team evaluated each component illustrated in the schematic individually and wrote the tasks accordingly. These tasks included inspections, replacements, and operational and functional checks of the various system components.

The OBGIS consists of several more components than the GBIS, requiring additional tasks and substantially increasing the added labor-hours required in the 2C- and heavy checks. The team assigned these tasks to the various checks (A, C, 2C, and heavy) and also estimated the labor-hours for each task. Appendix F contains a complete list of these tasks. The team assumed that tasks completed at an A-check would also be completed at a C-check. Similar assumptions were made for the C-check and 2C-check tasks (i.e., they would be accomplished at the 2C-check and heavy check, respectively).

Because the size and complexity of the OBGIS concept made the system infeasible for existing turbofan, turboprop, and business jet category airplanes, we did not complete an analysis for these airplanes.

Additional Maintenance Labor-Hours

Figure 7-3 shows the estimate of additional scheduled maintenance labor-hours that would be required at each check to maintain an OBGIS.

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Small	3	4	18	51	50.55
Medium	3	4	18	55	48.31
Large	3	4	18	59	46.51

Figure 7-3. OBGIS Additional Scheduled Maintenance Hours

7.5.3 Unscheduled Maintenance

The OBGIS consists of approximately 26 major components and is significantly more complex than the GBIS. Like the full OBIGGS, the airplane system is self-sufficient, which is the reason for the increased complexity.

System Annual Use Rate

Although the OBGIS equipment is similar to that of the full OBIGGS, the operating philosophy is significantly different. Unlike OBIGGS, the classic OBGIS—although an onboard system—operates only while the airplane is at the gate. Therefore, the operating time of the OBGIS is significantly less than for full OBIGGS over the same period of time, reducing the wear and tear on system components. To account for the reduced operating time, the system annual use rate (fig. 7-4) for OBGIS is then a function of the typical gate time and number of daily operations for each airplane category.

Airplane category	Airplane use rate, flight-hours/year	OBGIS system operational time, hours/year
Large transport	4,081	1,095
Medium transport	2,792	1,278
Small transport	2,869	1,916
Regional turbofan	2,957	1,080
Regional turboprop	2,117	1,034
Business jet	500	365

Figure 7-4. OBGIS Annual Use Rate

System Reliability

As with the unscheduled maintenance analysis on the other system concepts, we based the reliability of OBGIS components primarily on a comparison with similar components currently in use on commercial airplanes. The significant decrease in the reliability level of the OBGIS, compared with that of the GBIS, is a result of increased system complexity. The increase in the number of parts and the introduction of lower reliability, higher maintenance components such as compressors and ASMs decrease the system reliability by a factor of 10 times. The OBGIS MTBUR was calculated to be 945 hr for the PSA system and 960 hr for the membrane system. The difference between the systems was the slightly higher reliability of the membrane ASM.

Because similar component reliability data for a range of component sizes was not available, the analysis assumes that the OBGIS reliability is the same for all airplane sizes. In reality, system reliability may vary with the system size but, for the purposes of this study, the variation is assumed to be well within the margin of error for the reliability estimate.

System Annual Failure Rate

The annual failure rate for the inerting system is a function of its reliability and the system annual use rate. Using the OBGIS annual use rate, the frequency of inerting system failures on each airplane was predicted to be approximately two failures per year for an OBGIS.

The system annual failure rate, shown in figure 7-5, is significant because it indicates how maintenance intensive the inerting system is and what level of impact the system will have on flight operations. In the case of the OBGIS, an operator with a fleet of 300 airplanes could expect to have to address 600 additional maintenance problems per year because of the inerting system.

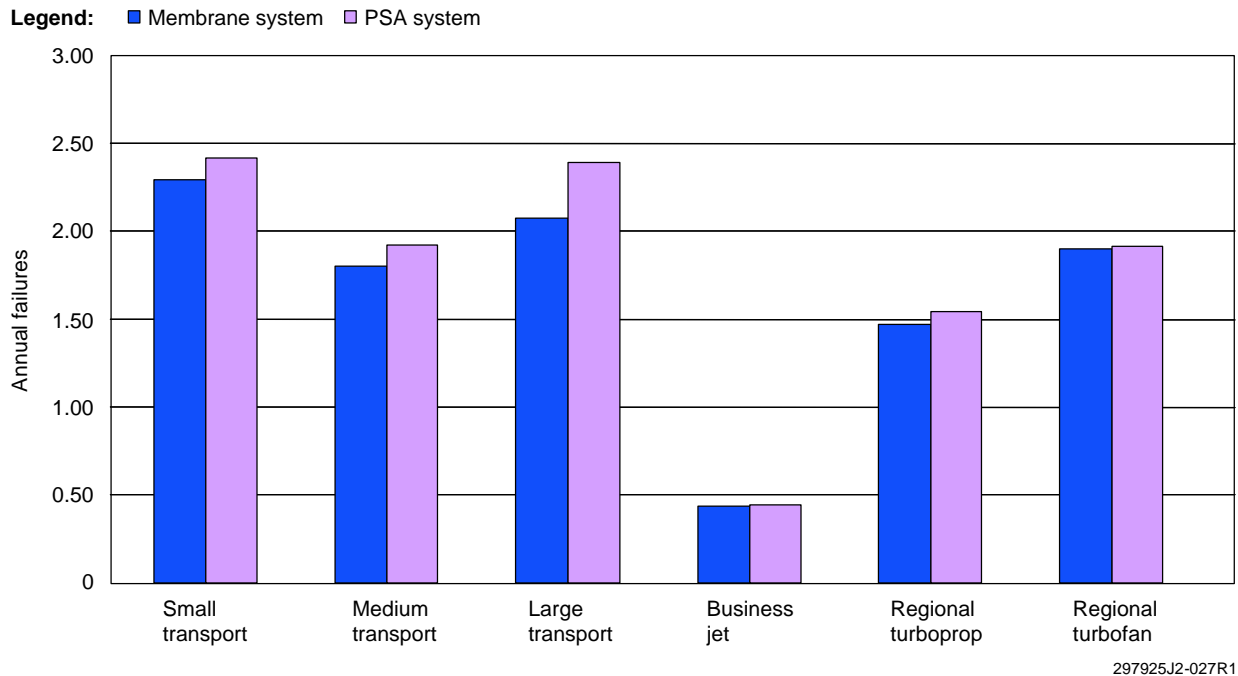


Figure 7-5. Predicted OBGIS Annual Failure Rate

Unscheduled Maintenance Labor Estimate

As with other system concepts, we surveyed potential component locations for each airplane category. Based on this survey, we developed estimates for troubleshooting, removal, and installation of each component. The tables in addendum F.C.2 of appendix F detail the troubleshooting, removal, and installation labor-hour assumptions. We also considered probable component locations, size, and weight in developing this estimate. We used the labor estimate and the component's predicted failure rate to estimate annual unscheduled maintenance labor rate for the OBGIS on each airplane category, summarized in figure 7-6.

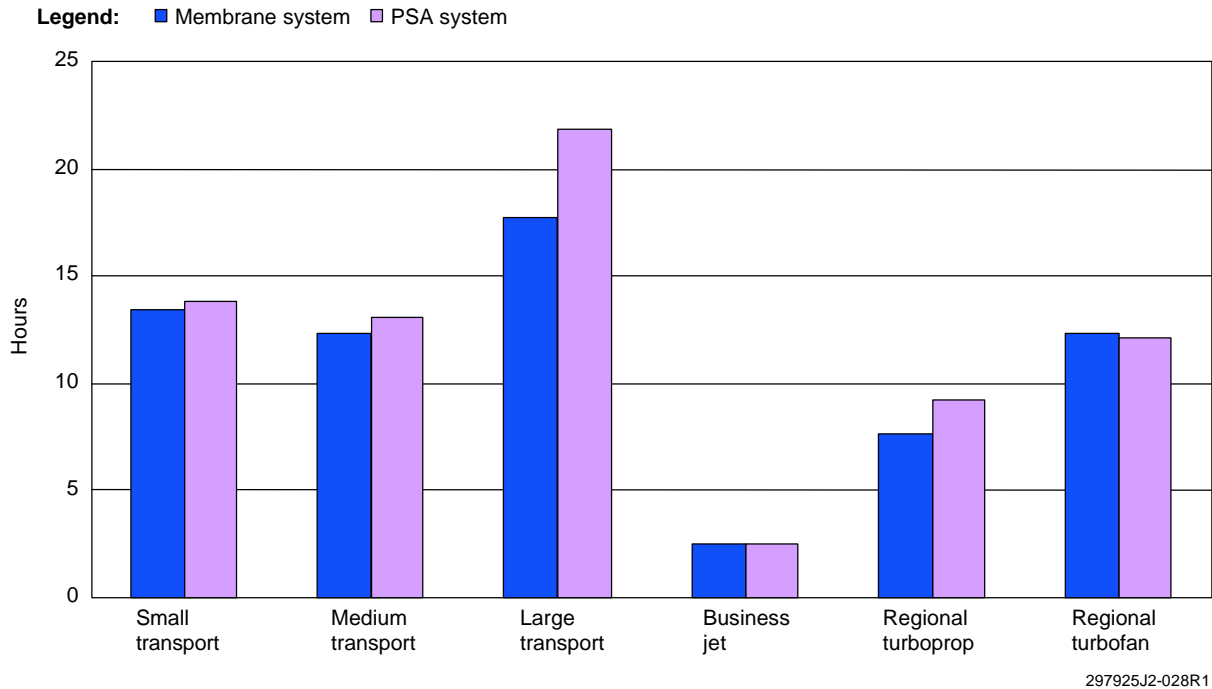
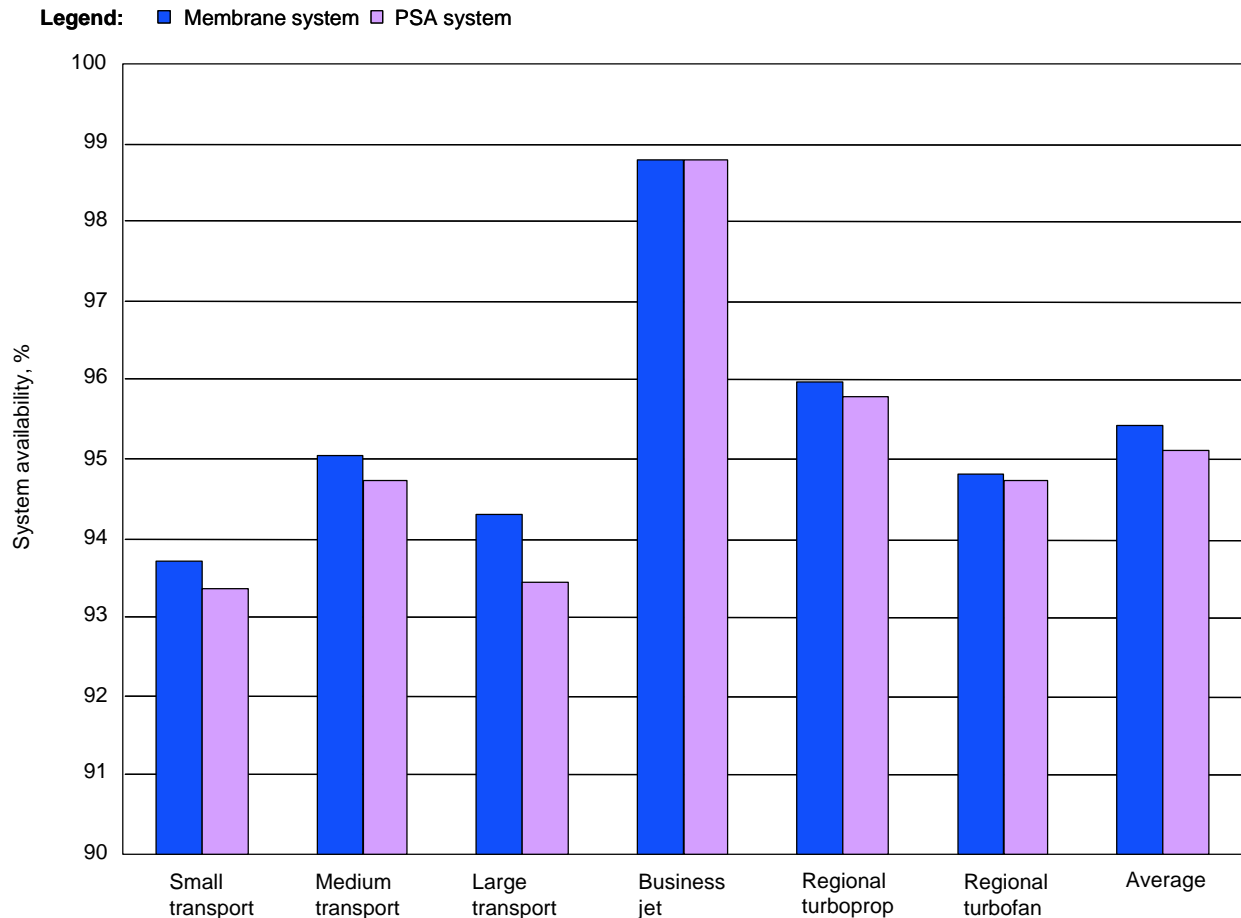


Figure 7-6. Annual Unscheduled Maintenance Labor Estimate per Airplane

Inerting System Availability

The OBGIS availability (fig. 7-7) is a function of the system reliability and the repair interval assumed for MEL dispatch relief. For example, if the system has an annual system failure rate of two failures per year and the MEL dispatch relief allows a 3-day repair interval, the inerting system may be assumed to be inoperative 6 days per year. Another way to look at system availability is as a percentage of departures. If the airplane typically has seven departures per day (as the small transport does), then the airplane would depart on 42 flights per year out of 2,555 with the inerting system inoperative. Assuming that an inerting system would remain inoperative for the maximum allowable number of days is a worst case scenario. In reality, the systems would likely spend 50% to 75% of the allowable time on MEL but, for the purposes of this study, we assumed that the full repair interval is used all the time. When considering the effect of the number of days a system is allowed to remain on MEL, decreasing the number of days improves system availability but comes at a price of increased flight delays, cancellations, and operating costs.



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Figure 7-7. OBGIS Availability

MEL Dispatch Relief Effect

Section 10.0 discusses the effect of the MEL dispatch relief assumption in detail. The availability of MEL dispatch relief for noncritical airplane systems and the length of time allowed before the system must be repaired have a large impact on the airplane's dispatch reliability and cost of operation. As an illustration, we calculated the number of delays and cancellations an operator might experience for a typical small transport airplane equipped with an OBGIS. This estimate is based on the projected OBGIS annual failure rate and some assumptions on the frequency of delays and cancellations based on a system failure.

If no MEL dispatch relief, shown in figure 7-8, is available, there is a high probability that system failure would result in multiple flight cancellations. If dispatch is available, the likelihood of flight delays and cancellations decreases as more time is allowed to route the airplane to a location where maintenance is available. The system can then be repaired during an overnight maintenance visit. The specific assumptions used here are based on typical operator experience and are presented in appendix F.

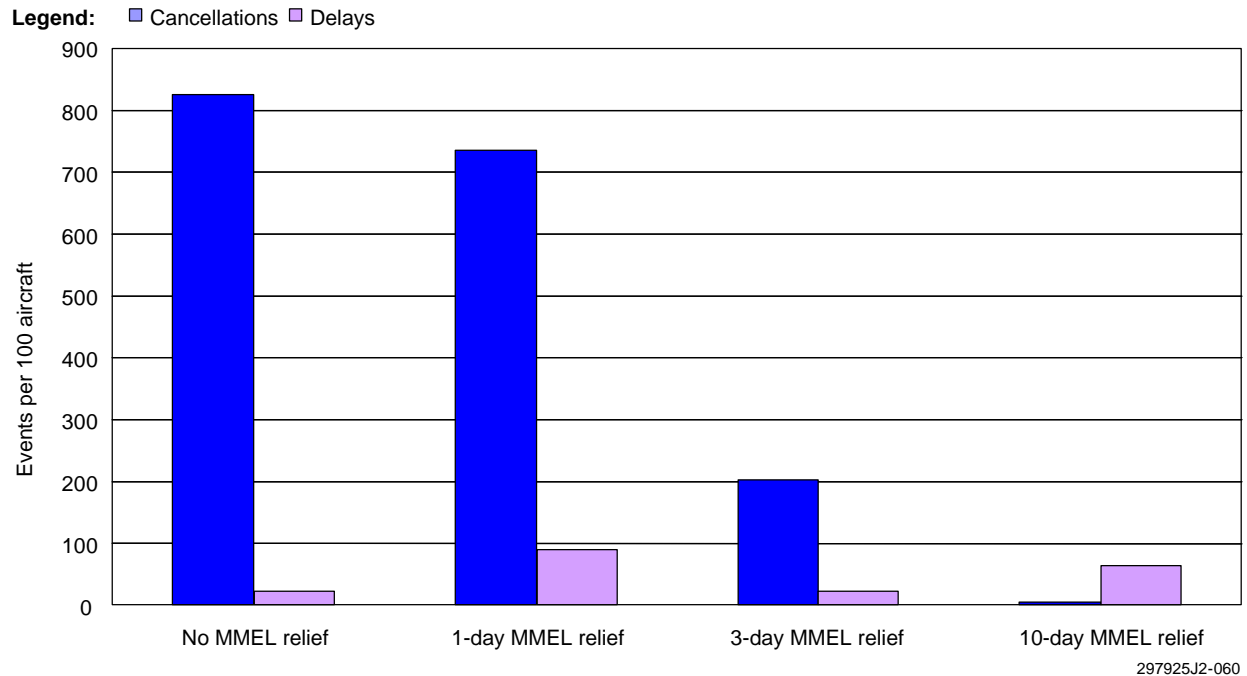


Figure 7-8. MEL Dispatch Relief Effect

Delay Hours per Year

The team estimated the effect of inerting system failures on flight departure schedules based on the OBGIS annual failure rate. Section 10.0 discusses the delay assumptions used for this estimate (fig. 7-9). Although not every system failure causes a delay, it is equally true that a single maintenance delay frequently causes multiple downline delays as a result of a cascade effect in the daily flight schedule. The number of delays and delay hours per year affect customer service. The airlines, through experience, have determined the impact of the reduction in customer satisfaction as a result of delays on operational revenue. Flight delays also affect operating costs through schedule changes, downline flight cancellations, and loss of passengers.

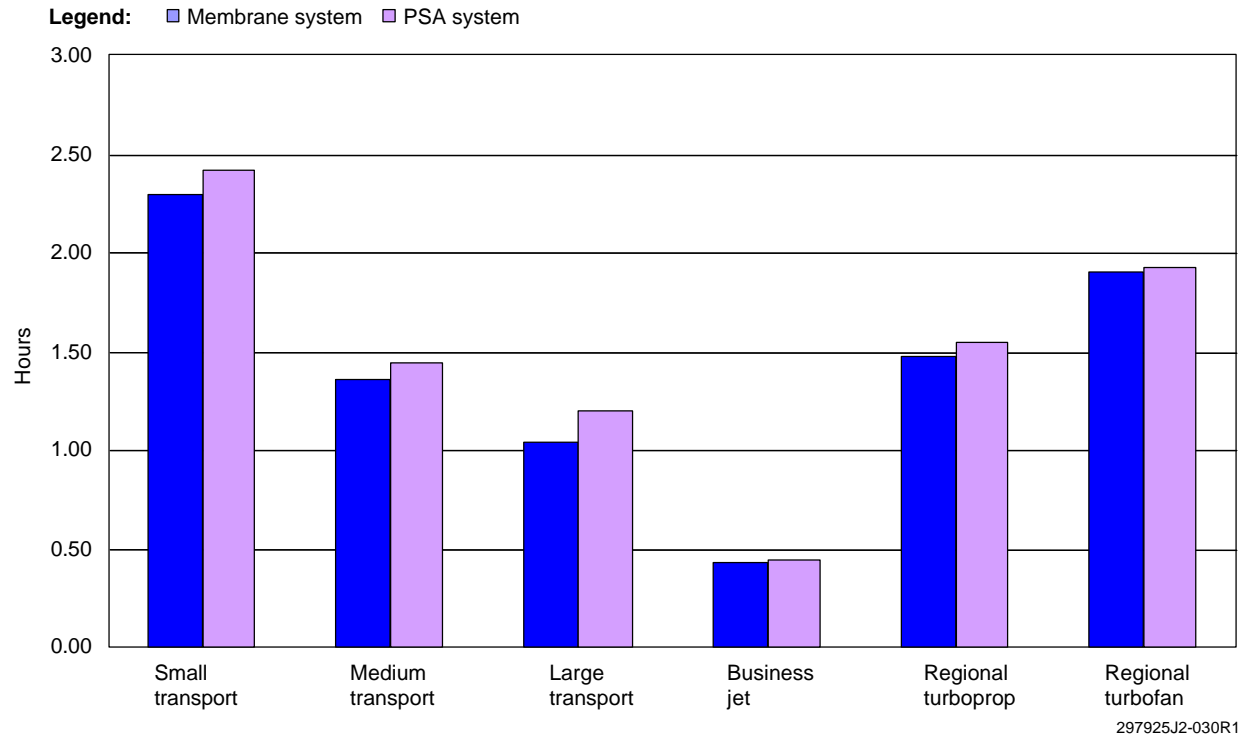


Figure 7-9. Annual OBGIS Flight Delay Hours

7.5.4 Flight Operations

The OBGIS allows for the availability of NEA for ground inerting techniques to be used at any airport that the airplane is deployed to if an adequate electrical power source is available. The system is designed to have adequate output to preclude delays beyond what are considered average minimum turn times for that airplane. The system is designed to require minimal activation and supervision by the flight crew with minimal cockpit indication and a simple on/off switch being redundant to automatic activation. Training for flight crews would serve to familiarize them with the system's benefits, functions, and characteristics. Additional training for crew and dispatchers would have to address MEL and dispatch provisions and requirements. The system should be designed to be fail-safe so that no hazard is presented by its operation to passenger or ground personnel.

A moderate weight penalty is incurred in carrying this system on board, which is manifested in additional fuel burn. However, there are no power drain requirements during flight.

7.5.5 Ground Operations

Both GBIS and OBGIS are operating only on the ground. The major difference between GBI and OBGIS is that inerting with the OBGIS is accomplished without the requirement for additional airport facilities, except for additional ground-power requirements. The OBGIS is a self-contained system.

Maintenance training requirements should be incorporated within the initial training programs similar to those discussed earlier, but tailored to this specific design. One concern that differs from the GBIS is that the OBGIS would require constant monitoring, particularly while fuel tanks are being inerted before the first flight of the day. The system design is such that the systems will have to be turned on 2 hr before the first flight of the day. Once power is put on the airplane and the inerting system is turned on, a normal safety procedure requires that a maintenance technician must monitor the airplane for problems. This does

not necessarily mean that a maintenance technician must sit in the cockpit, but someone must be close enough to respond to alarms or other problems. Activation and monitoring the airplane an hour earlier than is currently required adds significant work to line maintenance during an already busy time of day.

Other added responsibilities include making sure that the cabin is ventilated properly to ensure there is no possibility for nitrogen buildup in the cabin. These tasks would typically be the responsibility of the remain-overnight technician. In the event a flight crew member is not available, then a qualified technician should also monitor the inerting process during all through-flights. All other maintenance concerns typically go hand in hand with the concerns mentioned earlier for GBI.

7.6 SAFETY ASSESSMENT

Figures 7-10 and 7-11 show the impact that OBGIS could have on reducing future accidents in the United States and worldwide, respectively. If selected, the forecast assumes the system will be fully implemented by the year 2015 (see sec. 11.0 for implementation assumptions). At that time, the forecast indicates the time between accidents in the United States would be 16 years with SFAR alone, 31 years with SFAR and inerting in heated CWTs, and 33 years for SFAR and inerting in fuselage tanks. The corresponding time between accidents for the worldwide fleet would be approximately half that estimated for the U.S. fleet.

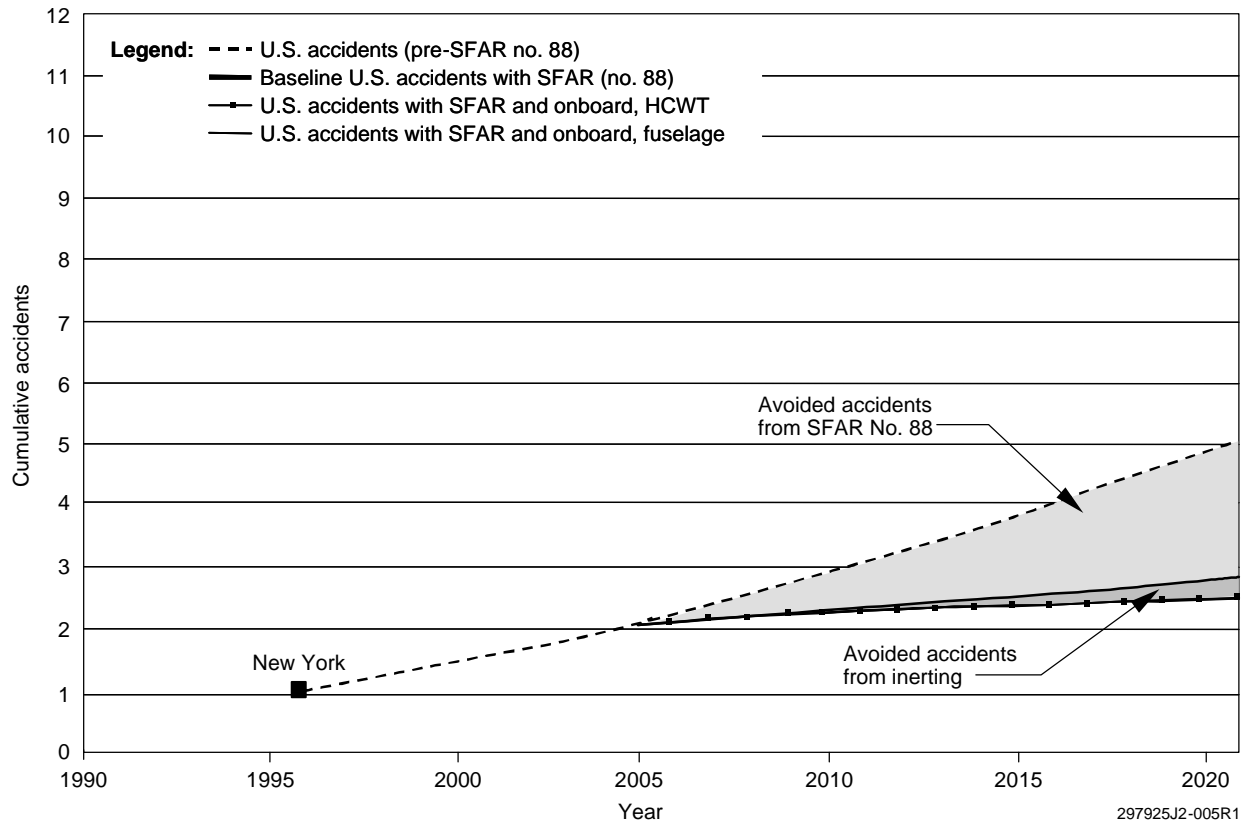


Figure 7-10. U.S. Cumulative Accidents With Onboard Ground Inerting

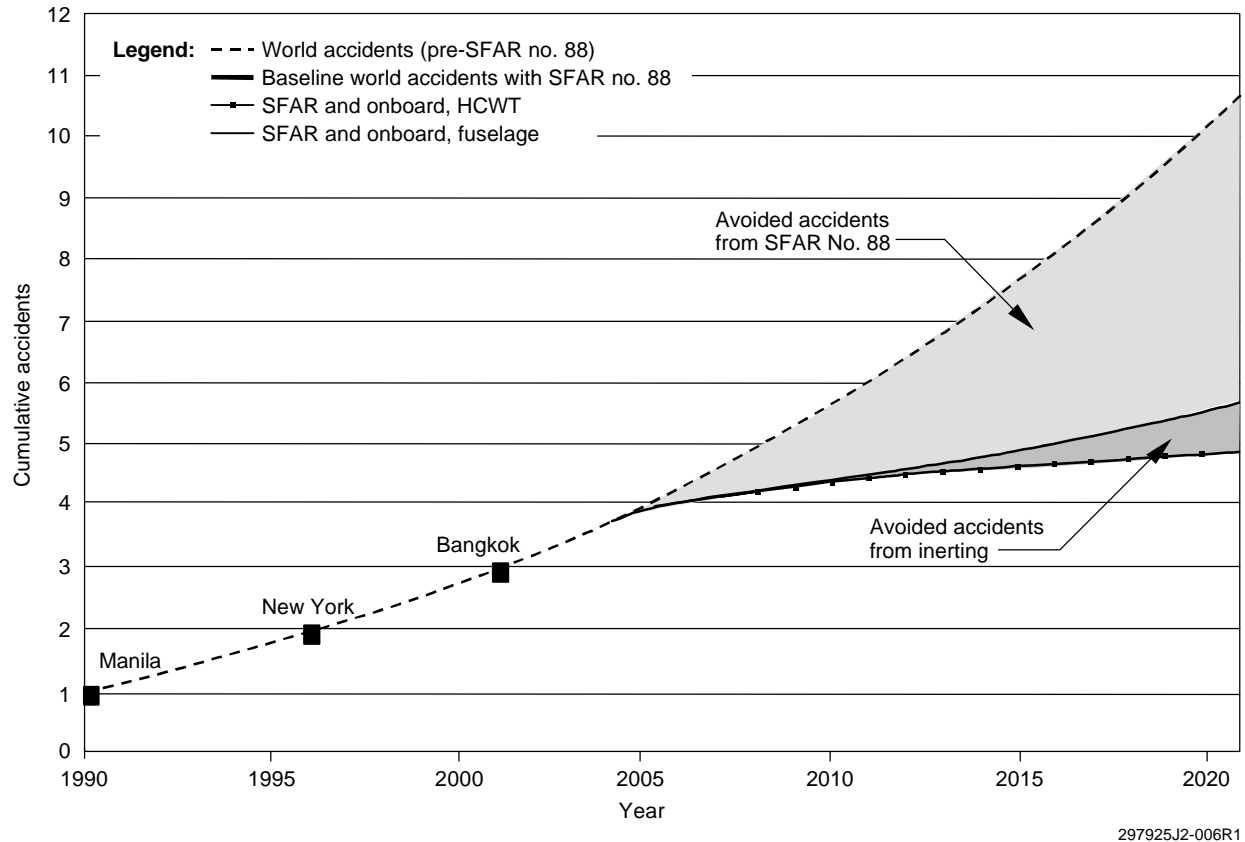


Figure 7-11. Worldwide Cumulative Accidents With Onboard Ground Inerting

7.7 COST-BENEFIT ANALYSIS

Figures 7-12 through 7-19 graphically represent the cost-benefit analyses of the scenario combination examined for onboard ground inerting.

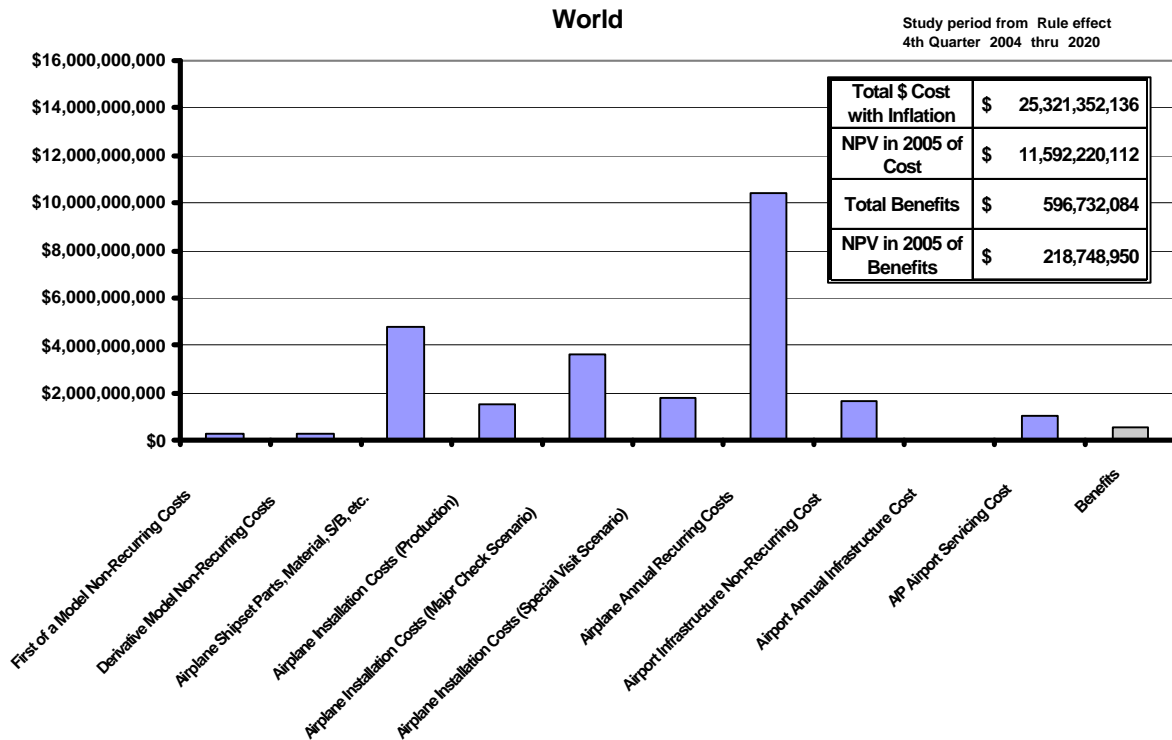


Figure 7-12. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (World)

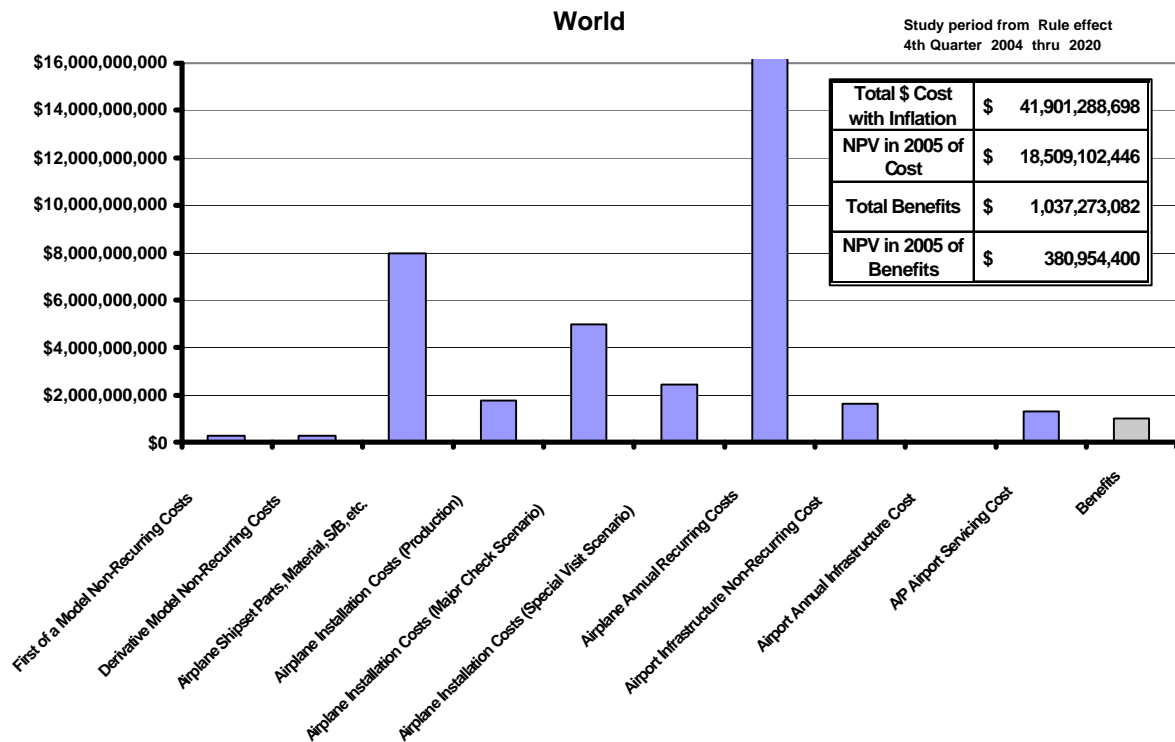


Figure 7-13. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World)

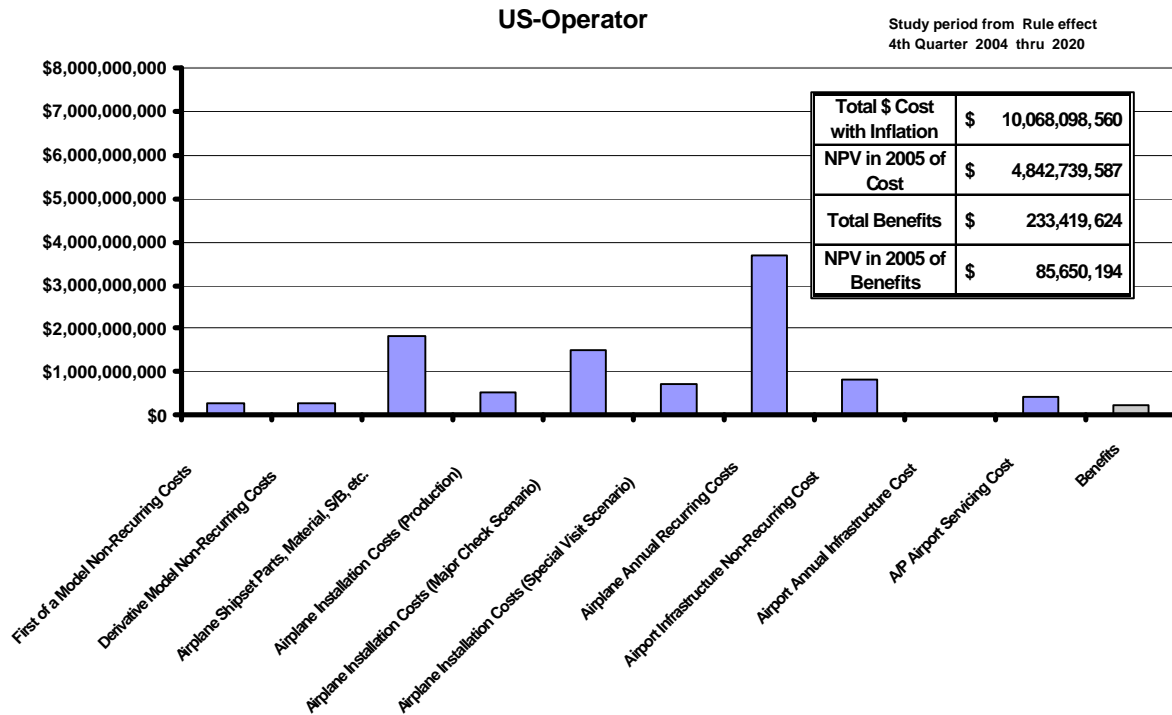


Figure 7-14. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (U.S.)

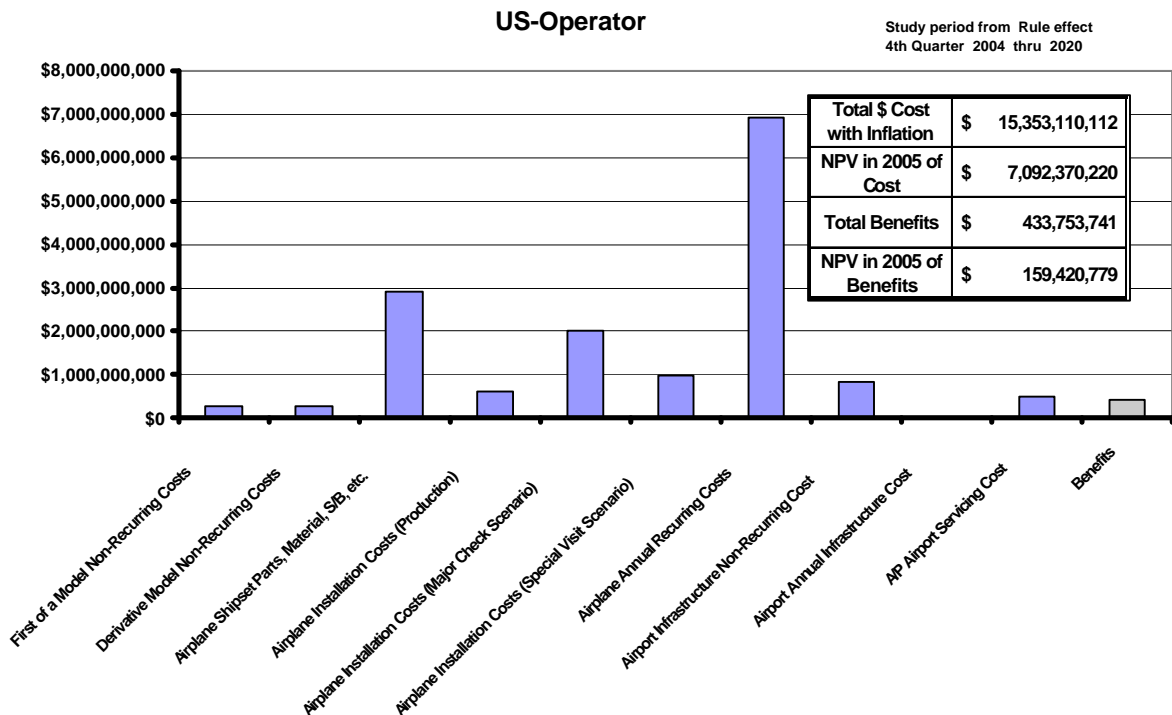


Figure 7-15. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (U.S.)

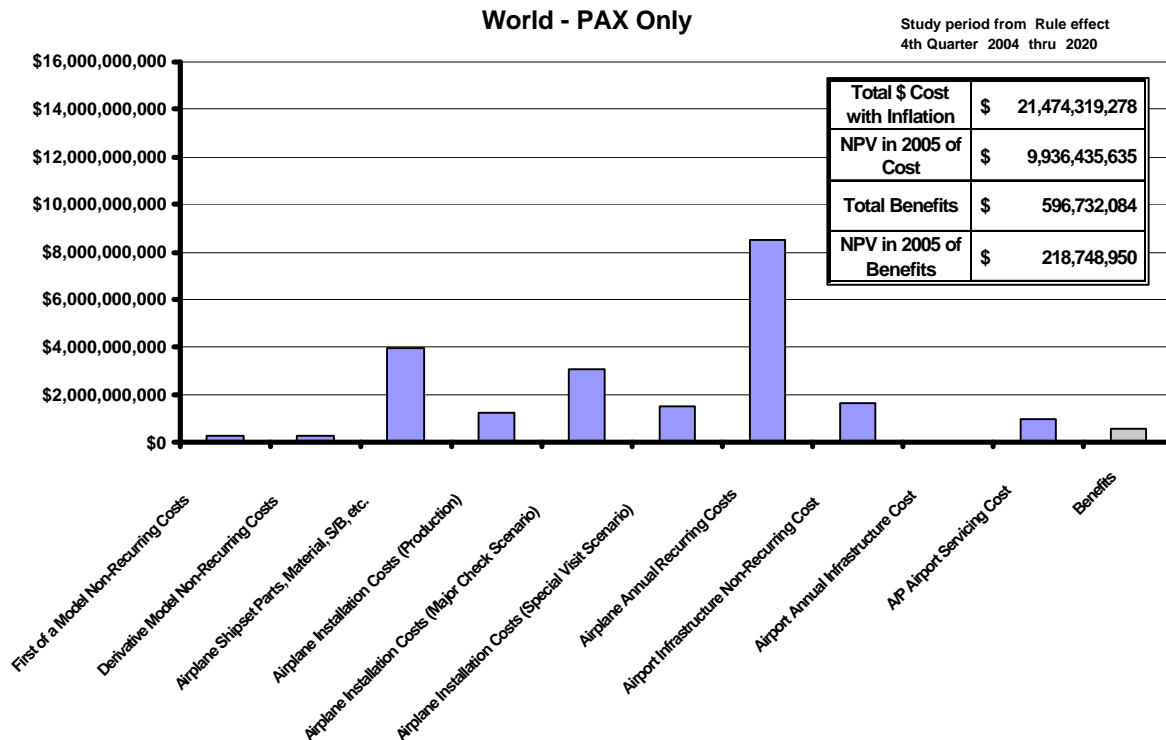


Figure 7-16. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (World, Passenger Only)

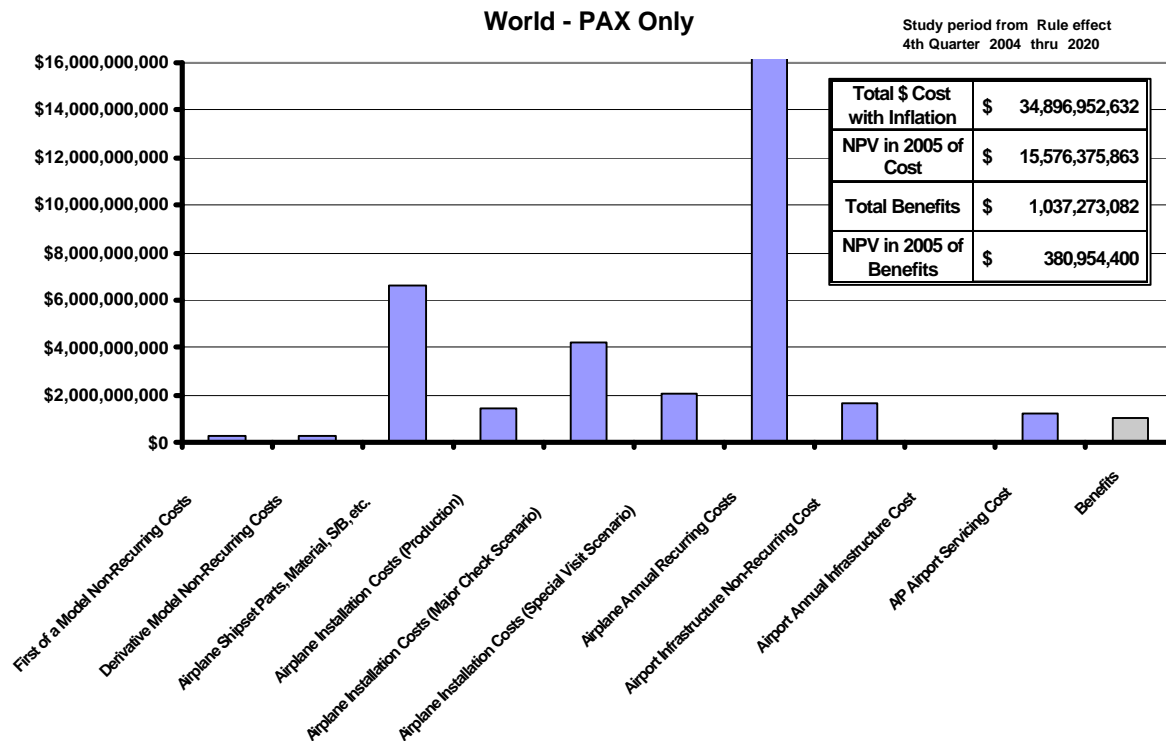


Figure 7-17. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World, Passenger Only)

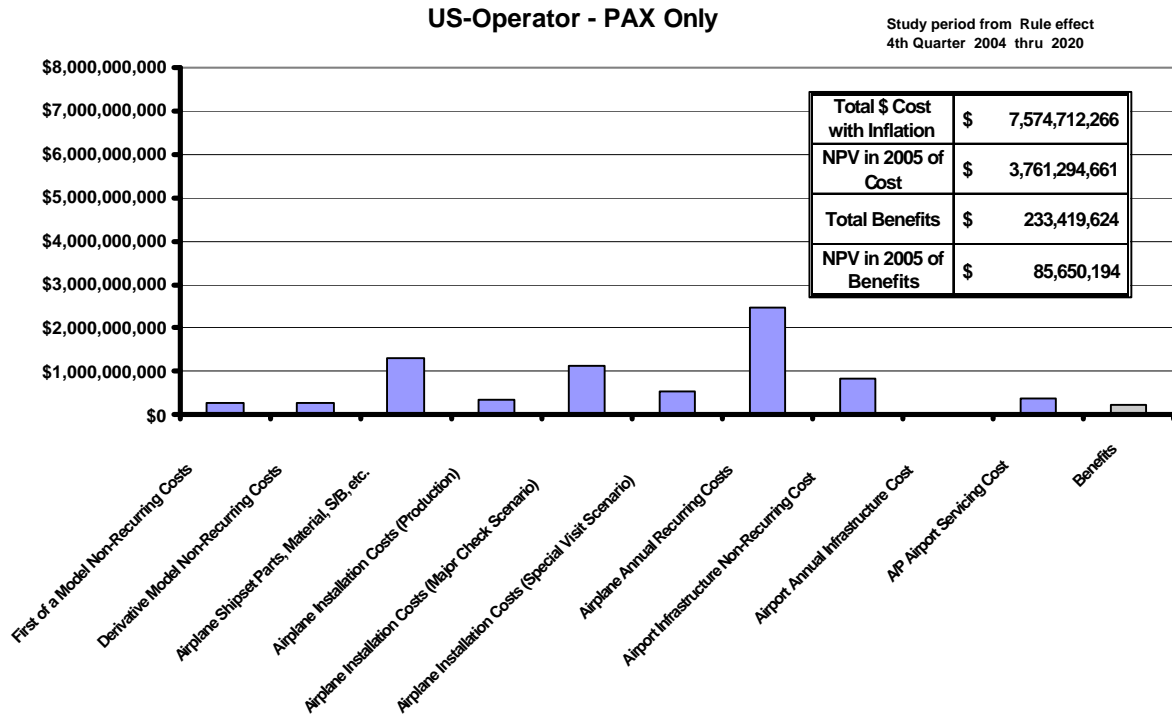


Figure 7-18. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

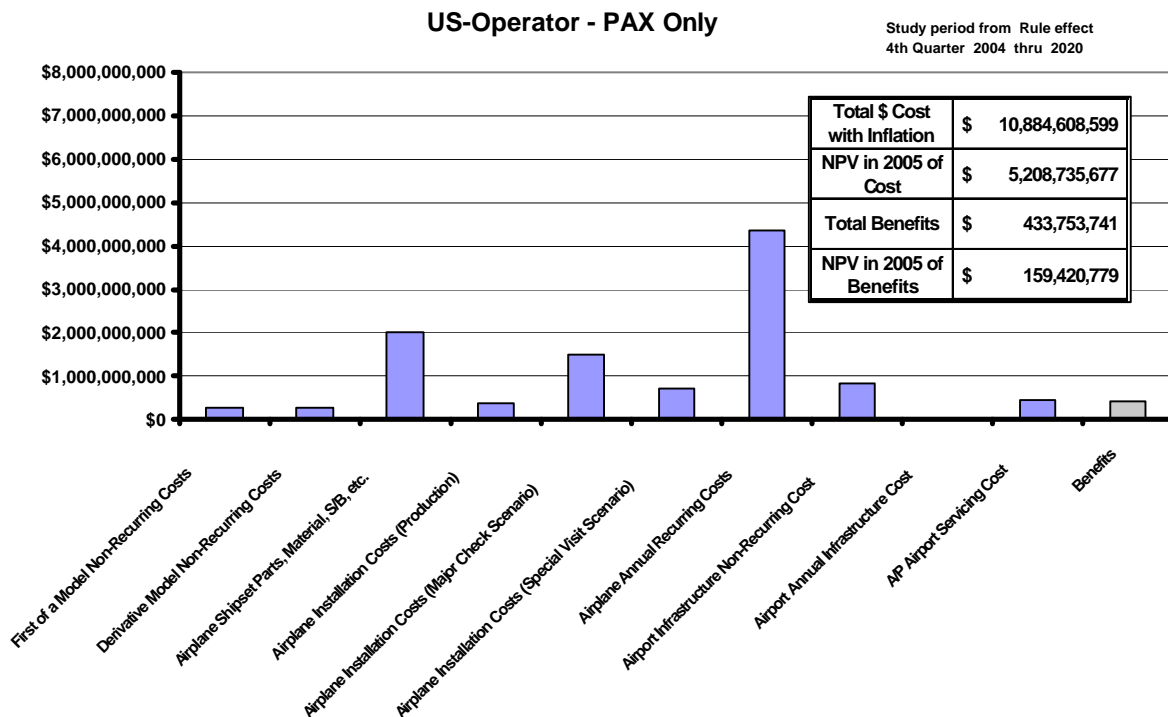


Figure 7-19. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

7.8 PROS AND CONS

Pros

- The OBGIS reduces total flammability exposure comparable with that of GBI.
- Certification is simpler than for an OBIGGS because it runs only on the ground, so interference with other airplane systems is minimized.
- The OBGIS potentially reduces corrosion and condensation in the fuel tanks, depending on where and how the operator uses the system.

Cons

- The OBGIS is the heaviest system studied, takes up the same or slightly more volume than full-time OBIGGS, and requires as much or more electrical power.
- The cost of components (only a part of the total system cost) far exceeds the potential benefit.
- Additional cost is incurred as a result of the weight of the system—which causes a fuel penalty—and airplane drag is increased because of inlet and exhaust ports for the system.
- The airplane's center of gravity may be adversely affected because of the system's location in some airplane models, which would also incur a fuel penalty.
- Compressor and fan noise may have to be damped, depending on local noise standards.

Indeterminate

Pollution:

- Normally, some fuel vapor exits the tanks during refueling, and some vapor will be pushed out when adding nitrogen to the tank.
- Fuel vent systems will need to be isolated to prevent crosswinds from diluting the nitrogen, which would be an improvement over present-day conditions.

No attempt was made to quantify this because of the complexity of the problem for each airplane model at each airport.

7.9 MAJOR ISSUES AND RESOLUTIONS

The technical limitations for retrofit of the OBGIS are its size, contamination issues with the ASMs, and a potential hazard with static electricity. The system size cannot be resolved without relaxing the requirements. A description of the improvements needed for the other limitations follows.

7.9.1 System Size

Some OBGIS issues relate to the large system size. For the large-transport CWT only, the system weighs between 500 and 1,000 lb (depending on the separator technology) and consumes almost all the power available from the APU generator. Little power remains for running the airplane's normal electrical equipment, such as lights, galleys, avionics, and their cooling fans, while on the ground (see fig. 7-20).

Legend: ■ Membrane system ■ PSA system

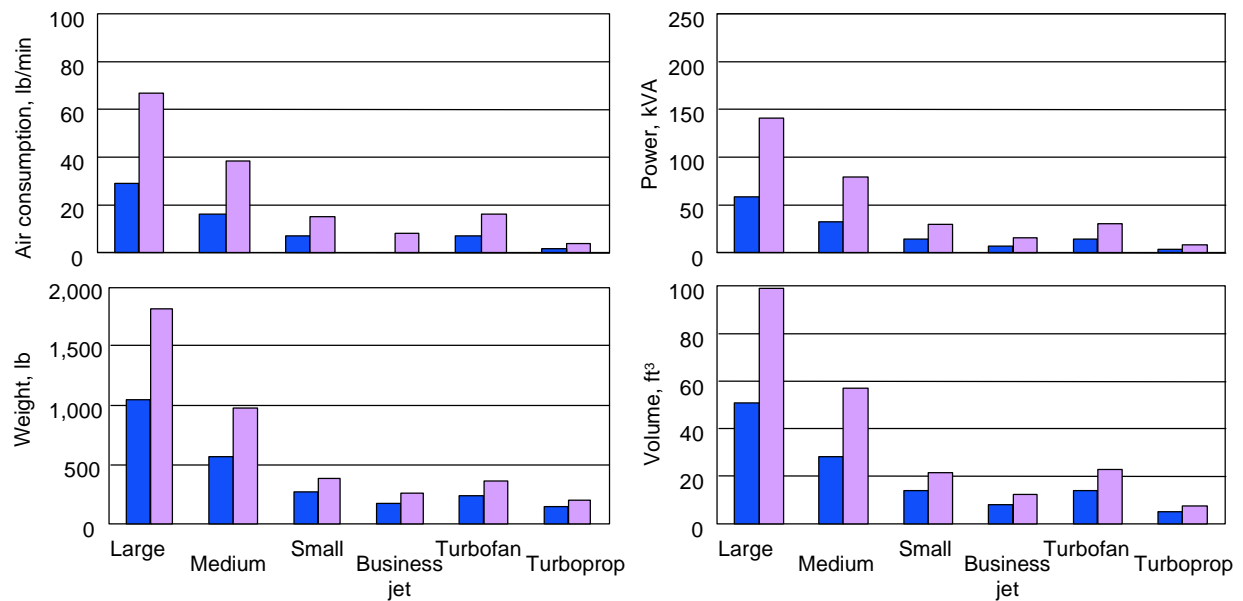


Figure 7-20. OBGI Required Resources for All Tanks

No matter what size the airplane, the system requires significant electrical power to run, may not fit in all airplanes because of its size, and is heavy. The only reasonable resolution is to increase the gate time, which will incur cost penalties for the operators.

Another issue is the compressor weight, which for the large and medium transports is too heavy for an average mechanic to lift. This can be resolved by changing the design to incorporate multiple compressors in parallel, making each compressor smaller and lighter but increasing overall volume.

7.9.2 Air Separator Modules

ASMs are susceptible to water contamination, which reduces performance. A water separator has been included in the design concept to avoid this problem.

Permeable membrane modules also are susceptible to hydrocarbon contamination from the fuel and oil vapor in engine bleed air. A coalescing filter has been included in the design concept to capture the vapor before it reaches the membrane.

In addition, permeable membranes have no service history onboard airplanes to prove their durability. They have been used in ground applications, however, where they have demonstrated a very long life.

7.9.3 Static Electricity

The rapid flow of dry gas in a distribution manifold inside the fuel tank can generate static electricity and cause sparks. This can be mitigated by using large-diameter manifolds to keep the gas velocity low and by bonding the manifold to structure (electrical ground).

7.10 CONCLUSIONS

The OBGIS reduces flammability exposure. But the concept suffers from the limited gate time available between flights and the large ullage volumes (small fuel load) required for short missions. The protection offered is approximately that of the ground-based concept but at a much higher price. Therefore, we do not recommend this concept.

